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# MAIN STAGE AND PRINCIPLES OF ORGANIZING THE PROCESS OF MATHEMATICAL MODELING

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**Annotation**
The main stages and principles of building a mathematical model are described in the article.

**Keywords:** object, parameter, system, process, subject, model, modeling, mathematical model, adequacy, hierarchy of models, algorithm, program, computational experiment.

One of the main requirements in mathematical modeling is the adequacy of the model. Adequacy of the model means that the results of the modeling and the results of the experiment with the object match. It should be emphasized here that the models that fully reflect the real situation are boring from a practical point of view. Thus, if the model can correctly reflect the data of real experience conducted on the object (process), such a model is called adequate.
Another important feature of the mathematical modeling process is that the model should reflect the most important features for the phenomenon (object, process), secondary factors (factors) are usually not taken into account. So, the mathematical model is a simplified representation of the real situation. As a result of such simplification, the given complex problem is reduced to an idealized problem that can be mathematically analyzed. For example, a heavy material ball attached to an inextensible thread - the mathematical idealization of the real object under consideration - the identification of important external factors in the study of the oscillation of a physical pendulum - leads to the concept of a mathematical pendulum.
A characteristic feature of the modeling process is the simplicity of the model. The main aspects of the built model should be understandable to practitioners. The first step in mathematical modeling is to create a simple model that reflects some of the most important properties of the phenomenon. This simple model is then generalized

to account for other external factors, and this process continues until an adequate "acceptable" solution is found.

It should also be said that striving for the simplicity of the models should not lead to conflict with the adequacy of the model to the real situation. In other words, in the process of building the model, it is necessary to correctly assess the field of its application. We will try to explain this aspect of mathematical modeling with the following simple, but important from the point of view of practical application, example.

At the initial moment moment = 0, the body at the height starts to move down with the initial velocity v0. It is necessary to find the law of motion of the body, that is, to build a mathematical model that describes the given problem mathematically and identifies the parameters of the movement at any time.

The mathematical model of the given problem has an important dependence on the accepted assumptions. In particular, we assume that the given body has an average density much higher than that of air, and that it has a shape close to a sphere. In this case, air resistance can be neglected and free fall with acceleration g can be considered. The appropriate relationship for height h and velocity v at any instant of time t is well known from a physics course. They look like this:

$$h = h_0 - v_0 t - \frac{gt^2}{2}, \quad v = v_0 + gt. \qquad (1)$$

These formulas are considered a mathematical model of free fall of a body. The applicability of this model is limited to the case where air resistance is not taken into account. Model (1) cannot be used in most problems of the motion of a body in the atmosphere of a planet, because when we use it, we can get wrong results. Among such problems, it is possible to indicate the movement of a drop, the entry of a low-density object into the atmosphere, about falling by parachute, and others. Here it is necessary to build a more accurate mathematical model that takes into account air resistance. If we denote by F(t) the resistive force acting on a body of mass m, then its movement can be expressed by the following equation:

$$m\frac{dv}{dt} = mg - F, \quad \frac{dh}{dt} = -v \ . \qquad (2)$$

To this system at t=0

$$v = v_0, \quad h = h_0 \ . \qquad (3)$$

initial conditions will need to be added.

Relationships (2) and (3) are a mathematical model for the problem of the movement of a body in the atmosphere. There are also other more complex models of similar problems (for example, the motion of a glider, etc.). It should also be noted that model (1) is derived from model (2) when F=0.

In modern studies of complex processes in nature, technology and human activity, mathematical models have a multi-level complex structure. For example, when studying the strength of a structure, for example, a bridge over a river, it is necessary to take into account the strength of its individual parts and elements in addition to the general static configuration of the bridge, which makes a solid body mechanics model necessary for individual elements.

Thus, there is the concept of a hierarchy of mathematical models. According to the principles of this hierarchy, a model at a lower level should not conflict with a model at a higher level. Mathematical models of concrete processes and simple phenomena are at the lowest level.

In the modeling of complex objects (systems), macromodeling - modeling the system as a whole at the level of subsystems and micromodeling - modeling the system or subsystem at the level of system elements are considered.

Any mathematical model works on specific assumptions. Failure to do so may lead to incorrect conclusions about the object. It should be noted that different models have different robustness properties, i.e., resistance to failure of assumptions. Conclusions and recommendations made on the basis of models with the property of robustness remain correct even with small deviations from the assumptions made. Model robustness is one of the most important requirements for mathematical models. Examples of robustness models include analysis of variance and regression models.

From the initial information about the model, we learned that a mathematical model consists of describing some properties of objects (phenomena) in the real world or in the field of research. Let's look at the following situation in order to understand in general the process of building the image of the object by the research subject using certain formal (mathematical) systems.

Let us assume that the object Q has some property C0 that we are interested in. To create a mathematical model representing this property, the following is necessary:

1. To determine the indicator of this property (that is, to determine the size of the property in a system of dimensions).

2. Define the list of properties S1,...,Sm, which are connected with the property S0 by some relationship (they can be the internal properties of the object and the properties of the external environment affecting the object).

3. In the selected format system, the properties of the external environment that affect the desired indicator Y are expressed as external factors x1,...,xn, the internal properties of the object as z1,...,zrparameters, and the properties that are not taken

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into account are expressed as unaccounted for (w1,..., ws) should be included in the group of factors.

4. If possible, determine the relationship between Y indicator and all factors and parameters to be taken into account, build a mathematical model.

An overview of such a modeling scheme is shown in Figure 1.

As shown in Figure 1, a real object is a functional relationship between its property indicators

$$Y=f(x_1,\dots,x_n,z_1,\dots,z_r,w_1,\dots,w_s). \qquad (4)$$

characterized by However, the model reflects only such factors and parameters of the object-original that are important for solving the problem under investigation.

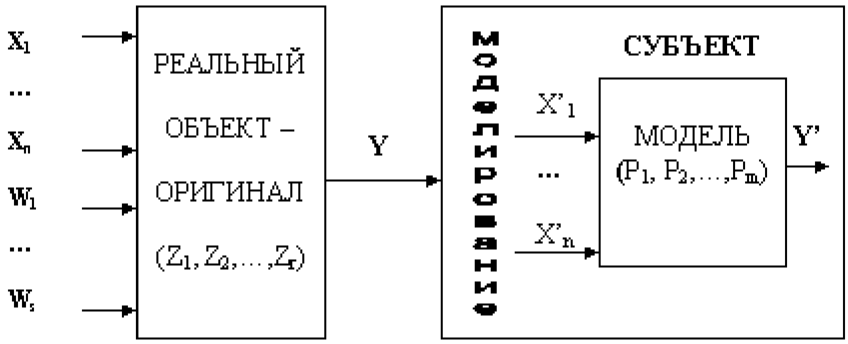


**Figure 1. Modeling as a subjective rendering of a real object.**

**In addition, due to the inaccuracy of measuring instruments and the lack of information about some factors, certain errors are definitely made in determining important factors and parameters. Therefore, the mathematical model is an approximate representation of the properties of the object being studied. A mathematical model can also be defined as an abstraction of the studied reality.**

**Models usually differ from the original in the nature of their internal parameters. The similarity in this is the adequacy of the Y reaction of the model and the original to changes in external factors x1,...xn. Therefore, in general, the mathematical model is described by the following function:**

$$Y' = f(x'_1,\dots,x'_n,p_1,\dots,p_m), \qquad (5)$$

Here p1,...,pm are the internal parameters of the model, which are adequate to the parameters of the original.

Depending on the application of the methods of mathematical description of the studied object, mathematical models can be analytical, simulated, logical, graphical, automatic and other similar forms.

The main issue of mathematical modeling is how accurately the created mathematical model reflects the relationship between the factors, parameters of the real object and the Y index of the evaluated property, that is, how accurately equation (5) corresponds to equation (4).

Sometimes equation (5) can be obtained in an exact form. For example, it can be formulated in the form of a system of differential equations or in the form of other specific mathematical relations.

In complex points, the form of equation (4) is unknown, and the task of the researcher is to find this equation first. In this case, variable parameters x'1,...,x'n include all external factors to be taken into account and parameters of the object under study, and internal parameters p1,...,pm of the model are included in the calculation of the sought parameters. These parameters connect the factors x'1,...,x'n, with the indicator Y' through the closest relation to the truth.

The theory of experiment deals with solving this problem. The essence of this theory is that based on the parameters x'1,...,x'n and the randomly selected values of the indicator Y', the function (5) provides the most accurate reflection of the real situation p1,...,pm, parameters are required to be found.

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